Microstructural transformations in magnetic hydrogels under flow-magnetic field coupling

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Magnetic soft matter, such as magnetic gels, elastomers, composites, and hydrogels that combine soft polymer networks with magnetic particles, is a versatile class of materials [1]. These materials are finding applications in an array of fields, ranging from soft robotics and adaptive materials to biomedical technologies, owing to their stimuli-responsiveness and ability to be controlled remotely [2–4]. Magnetic hydrogels are a common example of magnetic soft matter used in biomedical applications, for instance, for targeted drug delivery or bioprinted scaffolds. Often in such applications, magnetic hydrogels experience both shear flow and an external magnetic field. In this scenario, a rearrangement of both the polymeric network and the embedded magnetic particles is inevitable. However, there remains a limited understanding of the microscopic structural changes that occur within magnetic hydrogels during these scenarios. In this work, we developed glycyrrhizic acid (GA) hydrogels incorporated with superparamagnetic iron oxide nanoparticles, through a co-precipitation route, to investigate these transformations. GA is a bioderived, self-assembling polymer often used for drug delivery applications [5,6]. A rearrangement of the pure GA hydrogel and the magnetic GA hydrogel is observed under shear and an external magnetic field, through birefringence measurements (**Figure 1**). Furthermore, to understand the shear–magnetic force interactions, the nanoscale structure of the hydrogel is probed *in situ* under flow using small-angle neutron scattering (SANS). An in-house built setup, equipped with syringe pumps, flow control valves and flow channels, has been used with the SANS equipment, in combination with a magnetic field of 300 mT. An influence of the flow direction with respect to the magnetic field is observed on the particle alignment and anisotropy in the hydrogel. With this work, we strive to understand the effect of shear and magnetic field on magnetic GA hydrogels. Understanding the alterations in the microstructure of such hydrogels during their application phase, will help us design next-generation magnetic materials for biomedical applications.

Keywords:
magnetic hydrogel, neutron scattering, magnetic field, flow, nanoscale

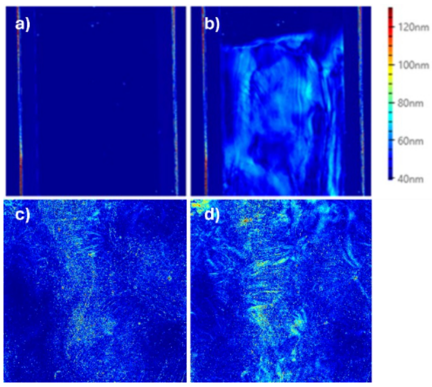

Figure 1: Retardation image of GA and magnetic-GA gels before and after application of shear. a) 23 mM GA after heated b) 23 mM GA after sheared using needle. c) 23 mM GA + 0.5 wt % Fe2O3 after heated d) under external magnetic field

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